Momentum and Impulse

The product of mass and velocity of an object is called its **momentum.** A very slow moving train can have the same momentum as a very fast moving student because both mass and velocity must be considered. The formula used is: $\vec{p} = m\vec{v}$

where p = momentum (kgm/s)
m = mass (kg)
v = velocity (m/s)

Example 1:
A baseball with a mass of 0.14 kg is moving at +35 m/s. a) Find its momentum. b)Find the velocity of a 7.26 kg bowling ball with the same momentum as the baseball.

$m = 0.14\ kg$
$\vec{V} = +35\ m/s$

a) $\vec{p} = m\vec{v}$
$= (0.14\ kg)(35\ m/s)$
$= +4.9\ kgm/s$

b) $m = 7.26\ kg$
$\vec{p} = +4.9\ kgm/s$

$\vec{p} = m\vec{v}$
$\frac{\vec{p}}{m} = \vec{v}$
$\frac{4.9\ kgm/s}{7.26\ kg} = \vec{v}$
$0.67\ m/s = \vec{v}$

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The **law of conservation of momentum** says that any momentum gained by one object in a collision must be equal to the momentum lost by another. Consider a billiard ball hitting a second billiard ball head on. The first one transfers its momentum to the second. The example problem below demonstrates what happens when the objects stick together.

Example 2:

A pellet from a gun hits a target filled with sand on an air track. The pellet stays inside the can and causes it to move at 30.0 cm/s. If the pellet had a mass of 0.50 g and the target had a mass of 100.0 g, calculate the velocity of the pellet just before hitting the target.

momentum before = momentum after

$m_p \vec{v}_p = (m_c + m_p)(v_{c+p})$

$(0.50\,g)(\vec{v}_p) = (100\,g + 0.50\,g)(30.0\,cm/s)$

$(0.50\,g)(\vec{v}_p) = (100.5\,g)(30.0\,cm/s)$

$\vec{v}_p = \frac{3015\,g\,cm/s}{0.50\,g}$

$\vec{v}_p = 6030\,cm/s = 60.3\,m/s$

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Impulse is the term we use to connect Newton's second law with momentum. It is the product of force and time interval.

$$\vec{J} = \vec{F}\Delta t$$

Recall that $a = \frac{v_f - v_i}{\Delta t}$

and $F = ma$

We can combine these to get a new formula for force.

$$F = \frac{m(v_f - v_i)}{\Delta t}$$

Notice that rearranging this gives us

$$F\Delta t = m(v_f - v_i)$$

or $F\Delta t = m\Delta v$

$$\Delta\vec{p} = \vec{p}_f - \vec{p}_i$$

This tells us that Impulse also equals the change in momentum

When we apply a force to an object for a period of time, its velocity changes and as a result its momentum changes.

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We will chose which equation to use to find impulse based on the information given in the question.

$\vec{J} = F\Delta t$

or $\vec{J} = m\Delta\vec{v}$ [$\Delta\vec{v}$ means $v_f - v_i$]

the units are

Ns

or $kg\,m/s$, the same as momentum

Example 1:
A 0.144 kg baseball is moving at +38.0 m/s. The batter hits it and it moves at -38.0 m/s.
a) Find impulse
b) Find the force exerted by the bat if contact was for 0.80 ms
c) Find the average acceleration of the ball during contact

a) $m = 0.144\ kg$
$V_i = +38.0\ m/s$
$V_f = -38.0\ m/s$

$\vec{J} = m\Delta V$
$\vec{J} = m(V_f - V_i)$
$\vec{J} = (0.144\ kg)(-38.0\ m/s - 38.0\ m/s)$
$\vec{J} = (0.144\ kg)(-76.0\ m/s)$
$\vec{J} = -11\ kg\,m/s$

b) $F = ?$
$t = 0.80\ ms = \frac{0.80}{1000}\ s = 8.0 \times 10^{-4}\ s$
$\vec{J} = -11\ kg\,m/s$

$\vec{J} = F\Delta t$
$\frac{\vec{J}}{\Delta t} = F$
$\frac{-11\ kg\,m/s}{8.0 \times 10^{-4}\ s} = F$
$-1.4 \times 10^4\ N = F$

c) $F = -1.4 \times 10^4\ N$
$m = 0.144\ kg$
$a = ?$

$F = ma$
$\frac{F}{m} = a$
$\frac{-1.4 \times 10^4\ N}{0.144\ kg} = a$
$-9.7 \times 10^4\ m/s^2 = a$

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